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WOUNDS AND INJURIES OF THE SOFT TISSUES

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PREFACE

This paper was submitted to the Office of the Surgeon General of the Army in September 1986 in response to a request by COL Thomas Bowen MC USA of the Surgeon General's staff that Dr. Fackler revise/rewrite "Wounds and Injuries of the Soft Tissues" (Chapter XVI from the 1975 edition of the NATO HANDBOOK - EMERGENCY WAR SURGERY), for the upcoming revised edition. The chapter has been completely rewritten, and none of the wording or figures from the previous Chapter XVI have been included. Since COL Bowen felt that the wording in the submitted chapter was too blunt or "confrontational," he and Dr. Fackler worked together to edit the chapter for publication.

The purpose of this institute Report is to preserve the chapter in the form it was submitted (and thus distinguish it from the edited chapter) and to clearly establish authorship, since authors' names will not be included with their contributions in the NATO HANDBOOK.

ABSTRACT

The projectile-tissue interaction has been explained and data showing the location of tissue disruption for various projectiles has been presented in the form of wound profiles. The major misconceptions in understanding of missile caused wounds and their treatment have been analyzed and their error exposed using wound profiles and other known data.

key words: gunshot wounds, injury, perforating wounds, high velocity missile, military medicine, kinetic energy transfer.

CHAPTER XVI - WOUNDS AND INJURIES OF THE SOFT TISSUES

The focus of this chapter is on what to do with damaged muscle. Maximum conservation of tissue is the guideline in treatment of damaged skin, and other soft tissues are covered in other chapters.

PATHOLOGY IN OPEN OR PENETRATING INJURY

CRUSHED MUSCLE: Muscle may have its gross anatomy severely disrupted by multiple penetrating projectiles striking in close proximity to each other, as caused by explosive device injuries, fragmenting rifle projectiles, or any rifle projectile that strikes bone (see Chapter II). Some remnants of muscle crushed by penetrating projectiles will generally be seen as a frayed edge of the projectile hole. Detached pieces of muscle, partially detached muscle flaps and muscle islands surrounded by perforations should be regarded as nonviable. They would most likely act as foreign bodies and potentiate infection in an already contaminated wound. The amount of crushed muscle resulting from a single bullet or fragment is closely related to the size of the projectile.

STRETCHED MUSCLE: Temporary displacement of muscle by cavitation (see Chapter II) can cause petechial hemorrhages from torn small vessels (contusion), thrombosis of other small vessels and patchy broken muscle fibers. Cavitation follows the path of least resistance, which is most often to separate muscle between parallel fibers and bundles. Gross radial splits are sometimes seen in muscle but not nearly to the extent they are seen in skin.

THE HEALING PROCESS AND FACTORS THAT AFFECT IT

Where one draws the line in excising muscle surrounding a missile path has been the subject of intense debate in wound ballistics. The 5th CINC PAC War Surgery Conference (Tokyo, Japan 1971) stated "...the surgeon must choose between leaving tissue of questionable viability or causing morbidity by removing viable and functional tissue." Most other opinions of the past two decades have

held that "complete excision of all devitalized tissue is mandatory","Bold removal of all devitalized muscle is imperative"(NATO Handbook, 1975), and that deformity or dysfunction resulting from such "bold" operations is justified.

The assumption that nonviable muscle can be identified by its dark color, "mushy" consistency, lack of contraction when pinched with a forceps, or lack of brisk bleeding from a cut surface, has been repeated so often that many assume it is supported by scientific fact. Such is not the case. In all studies in which animals were kept alive long enough to observe and measure healing objectively, or evaluate the pathology around missile wounds microscopically, there was less lasting tissue damage than estimated from observation of the wound in the first few hours after wounds were inflicted (Harvey, 1948, Dzemian, Mendelson, Lindsey,1961, Hopkinson, Watts, 1963, Mendelson, Glover, 1967, Ziervogel, 1979, Wang, Qian, Zhan, 1982, Breteau, Fackler, Courbil, 1986).

Development of life-threatening gas gangrene is the complication most often cited to justify recommendations of "radical debridement" or wide excision of muscle. Of 224,080 wounded in France in WW I, those with soft tissue injury and no bone fracture developed gas gangrene in only one percent of cases and less than half of these were fatal. A streptococcal bacteremia was by far the most common cause of death. Many of the less than one-half-of-one percent of deaths attributed to clostridia were suspected to have been due, in reality, to undetected streptococcus (Ireland, 1929). Streptolysin elaborated by the virulent streptococcus species breaks down the fibrin deposited by the body in an attempt to wall off pathologic bacteria collections. This made generalized streptococcal spread impossible to control in the pre-antibiotic era.

Since the discovery of antibiotics, streptococcal bacteremia has all but disappeared from the battlefield because of antibiotics, a fact overlooked by those who suggest that antibiotic therapy is only an ancillary measure in the management of combat wounds.

Consider a perforating thigh wound from an AK-74 (see Chapter II), in which the bullet path is well away from major vessels and there is no bony damage. The entrance is a punctate skin hole a few mm in diameter, and the exit is a stellate wound measuring 11 cm from the tips of opposite

skin splits. The maximum muscle disruption is easily visible just under the gaping skin opening and measures about 6 cm in diameter. The wound is not bleeding, the casualty can walk but with a limp, vital signs are normal. What are the threats if no treatment is given? Certainly a localized infection of the contaminated exposed muscle must be expected. What is the likelihood that this infection will threaten the life of the casualty? Let us assume that penicillin is given to this hypothetical casualty. The first injection is given 30 minutes after the wound was inflicted and the course of treatment lasts for five days. What will be the course of the wound pathology if no other treatment is given? Healing mechanisms would be focused on the area, first in the form of increased blood flow; any devitalized tissue that could not be ingested by phagocytes would then be walled off and eventually expelled through the open exit wound (about 11 days after wounding). Wound edges would then contract rapidly and the wound would close itself by about 25 days. During the healing period the casualty could walk well on the injured leg - after three days the limp would be gone - he would remain afebrile and could perform light duties. He would wear a simple dry gauze dressing over the wound until healing was complete.

The course of events just described is not only what one would expect from knowledge of trauma pathology and the physiology of wound healing, it describes events observed recently in a study of AK-74 leg wounds in 90 kg swine (Breteau, Fackler, Courbil, 1986).

It has long been recognized that pressure from a confined abscess or from muscle swelling secondary to body defense mechanisms reacting to localized tissue disruption could result in more local tissue necrosis and spreading of infection. Mechanical pressure high enough to disrupt local blood flow will kill additional tissue. Incision for drainage of an abscess or fasciotomy to relieve mechanical pressure on muscle gives the body's defenses access to the wounded area through increased blood flow. The highly successful incisional treatment of wounds was called "debridement" by the French. The word was adopted into other languages, but somewhere in the process "debridement" came to be used in English as a synonym for "wound excision". The uncomplicated soft tissue AK-74 extremity wounds needed no surgical intervention to establish excellent drainage - this had already been accomplished by the temporary cavitation stretch caused by

passage of this bullet (see Chapter II). Most who have seen gaping stellate exit wounds produced by the modern generation assault rifles (M-16, AK-74, French FAMAS, etc.) have assumed that this damage indicated a need for wider or more radical wound excision. Very few understood wounding mechanisms and the course of wound pathology well enough to recognize the beneficial effect of this "debridement par balle" --establishment of excellent open drainage by the bullet itself. The excellent healing of these wounds was not improved upon by the addition of "wound excision" (Breteau, Fackler, Courbil, 1986).

From the time a wound is inflicted until healing is complete, the surrounding area is in a state of constant change. In the first few hours after an extremity is exposed to the violent temporary cavity stretch of the AK-74 wound, a marked vasoconstriction of these tissues is revealed by skin blanching for a distance of 6 to 8 cm from the skin edges. Marked hyperemia appears around the blanched area and gradually encroaches upon it, eventually replacing it entirely in about four hours (Breteau, Fackler, Courbil, 1986). Although less dramatic than the skin changes, increasing perfusion of muscle surrounding missile paths for up to 72 hours after wounding has been clearly established (Wang, et al, 1982, Ziervogel, 1979).

Since blood flow in the muscle around the projectile path is changing, how can the surgeon, at any point in time, using any set of guidelines, be assured that he is excising nonviable and leaving viable muscle? The answer is, of course, that he cannot. Writings in the past two decades have demanded this judgment of our young surgeons when even the most experienced combat surgeon cannot perform it with certainty. This was demonstrated in the Vietnam conflict when a wound was treated in accordance with the oft repeated "4 c's" guidelines (color, contraction, consistency, circulation) and then on arrival at another hospital a few days later obviously necrotic muscle was observed in the wound. Many were vociferous in their complaints that the initial surgery had been done improperly. The 5th CINCPAC War Surgery Conference in 1971, corrected this misconception by including a statement that later appearance of necrotic tissue in a wound "does not necessarily mean that the original debridement was improperly done". This same phenomenon was seen in the recent controlled study on AK-74 wound treatment, in which every wound excision combined the expertise of two experienced combat surgeons (one French

and one American). In 40% of cases more necrotic muscle became evident several days after the surgeons excised all tissue that fit the commonly used criteria.

All of the factors that slow or prevent healing (negative nitrogen balance, immunodeficiency, vitamin deficiency, diabetes mellitus, old age, parasitic infestation, etc.) can affect how much necrotic tissue can be absorbed by mechanisms such as phagocytosis. Where the line will be drawn in separating and expelling nonviable tissue may also be affected by concomitant trauma. In laboratory studies, 25% blood volume hemorrhage has been shown to decrease perfusion of muscle around penetrating missile wounds (Almskog, et al. 1983), and significant other trauma might well be expected to decrease the body defense resources available to any given wound. This might be thought of as analogous to burn trauma where quantification shows clearly that an individual 3% burn heals quite well but that same burn does less well if 70% of the rest of the body has been burned also.

TREATMENT RECOMMENDATIONS

Choice of treatment should be based on:
1) Preserving life
2) Preserving function and minimizing disability
3) Minimizing healing time
4) Efficient use of treatment resources.

Establishment of an adequate blood level of penicillin or an antibiotic with a similar spectrum as soon as possible after wounding, and incision, if needed, to relieve mechanical pressure and establish open drainage, are top treatment priorities. Excision of muscle whose gross architecture is visibly and obviously severely disrupted should also be done when possible.

Steps in the surgical treatment of the extremity wound that does not involve bone or major vessels or the trunk wound that does not penetrate a visceral cavity: (Most likely only local anesthesia will be needed, with concomitant decrease in risk)

1. Excise small punctate entrance or exit wounds with a small ellipse of skin oriented parallel to the underlying muscle fibers (not over 2-3 mm of skin from edge of

wound).
2) Through this opening look at the hole extending into the muscle, split muscle fascia parallel to the muscle fibers in both directions from the missile path to open the deeper areas for drainage and to look for expanding hematoma, unsuspected muscle disruption, or foreign bodies. If conditions dictate, extend incisions parallel to the extremity long axis (cutting across muscle bundles at right angles to their fibers would almost certainly cause unnecessary disability).
3) Irrigate copiously; remove foreign bodies, blood clots, any detached muscle pieces (as seen with fragmenting bullet wounds) or muscle that is obviously severely disrupted.
4) As a dressing, dry sterile gauze should be laid lightly in the wound (this should be no more than a wick) - in no case should gauze be "packed" into the wound since this additional pressure could cause necrosis to tissue that might already have its blood supply partially disrupted.
5) All wounds must be left widely open, with the following possible exceptions:
   a. Sucking chest wounds
   b. Some head and neck wounds (in questionable cases, such as those with severe contamination, it is safer to leave them open)
6) Closure of the wound with tape can begin as early as 4 days after wounding. Approximate skin edges with micropore paper tape applied in overlapping diagonal "basket weave" fashion after the skin has been degreased with alcohol or acetone and tincture of benzoin has been applied and allowed to dry thoroughly. Edges of the wound may not come completely together with the first tape application. This is not a problem, it will come progressively closer together with each reapplication of tape, done at 48 hour intervals. Tape closure offers major advantages over suture closure. Even compression of wound edges decreases skin edema and the problem of sutures causing additional damage by cutting through tissue is avoided. The wound edges are very vascular and suture holes can cause hematomas. Since tape closure is, in reality, a gradual "encouragement" of the skin toward closure rather than a total closure from the beginning, a great margin for error is added and the common complication of wound breakdown, often seen after suture closure, is almost completely avoided. No anesthesia is needed for this procedure and it can be done by ward nursing personnel.

In some wartime situations medical care to the wounded may be delayed up to several days. Wounds seen late, with obvious necrotic muscle, may offend the surgeon's sense of neatness. Before attacking these wounds surgically, look at the whole patient. Is he febrile, toxic, or otherwise healthy? Certainly antibiotic coverage should be started if not already begun. If the body's defenses appear to be handling the wound well, at least consider the option of simply cleansing and then dressing the wound daily. If necrotic tissue is present which the body cannot absorb, it will separate, life and maximal function will be preserved. The viable tissue margin adjacent to this necrotic tissue is likely to be very vascular. Surgery will be bloody and may hinder the body's healing process at this point rather than helping it. Consider that in this same situation if the necrotic tissue were buried, as with an abscess, incision for drainage would be the proper treatment, and it would create exactly the situation with which you are presented.

Buried muscle disruptions in the extremities are readily diagnosed using physical examination findings and confirmed with biplanar x-rays. A collection of small metallic fragments along a rifle wound path indicates marked muscle disruption (Fackler, et al. 1984). A cavity of over 4 cm diameter without metallic fragments can be caused by an early yawing AK-74 (see Chapter II), and this persists on repeat x-rays for up to a week post injury (Breteau, Fackler, Courbil, 1986). This indicator of injury should be especially useful after the early vasomotor responses (up to 6 hours post injury) have stabilized. Incision to drain these buried disruptions of the extremities is probably the treatment of choice although waiting and draining them later if needed might be acceptable under circumstances where good followup can be assured.

CLOSED INJURY OF MUSCLE

Prolonged ischemia of a muscle group can produce serious effects both locally and systemically. Such ischemia may result from: continued direct compression, as in a patient trapped beneath debris; increased intracompartmental pressure from edema and hemorrhage following a direct crushing blow ,with or without fracture; or delay in correcting interruption of arterial blood supply from laceration, embolus or thrombosis.

PATHOLOGY

Direct damage to muscle from mechanical pressure or damage from prolonged ischaemia can result in local swelling from extravasation of blood and plasma. Increased blood flow in response to the injury, as seen with penetrating injuries, can add to the pressure and cause further muscle necrosis.

The muscle mass involved is usually much greater than with penetrating muscle injury and thus the amount of muscle pigment, potassium, creatine and lactic acid liberated into the circulation is likely to be much greater. Coupled with hypotension, this can result in acute renal insufficiency (see Chapter X).

CLINICAL CONSIDERATIONS

Recognition of a threatening increase of intracompartmental pressure (to 30-40 mm Hg, the pressure at which capillaries collapse) is a clinical problem. Pain and paresis are poor guides; there may well be adequate other causes for discomfort and weakness confusing the issue. Presence of good pulses and good capillary refilling distal to the compartment involved is treacherous reassurance; what is compromised is capillaries and deep veins within the compartment, not the arteries. The clue which cannot be disregarded is distal hypesthesia in the distribution of a nerve which transits the compartment. Immediate fasciotomy is indicated.

The early splinting of major soft-tissue injuries and fractures is important to rest the part, and the limb should be kept cool by exposure to air (avoid unnecessary dressings). Keeping the limb quiet and cool should minimize release of deleterious intracellular substances.

CONCLUSION

It must be emphasized that there are degrees of tissue damage. Bruised tissue is not excised in other situations. Orthopedic surgeons do not feel compelled to excise all bloodstained muscle when doing an open reduction. Muscle can have its blood supply compromised, or be and bruised without becoming nonviable. Afforded a good environment for healing, complete recovery might be expected. One must, however, be aware of the tenuous situation and be wary of doing anything to this muscle

that can result in additional compromise- like using it to form a flap to cover some other structure. It is not surprising that recommendations for excising bruised muscle find no valid scientific support. What is surprising is that so many otherwise intelligent surgeons have accepted the increased morbidity that goes with recommendations for "radical" muscle excision without demanding solid evidence of benefit.

One cannot overemphasize the role of surgical judgment and good common sense in the handling of war casualties. The battlefield scenario may well impose limitations (lack of air superiority, etc.) causing delays in the delivery of medical care, medical treatment supplies may run out, surgery may be unavailable, etc. Just as triage is a constant balancing of treatment resources against the demands upon them, treatment of the individual casualty may become a trade-off of less than ideal choices. Treatment that accomplishes the desired goals in the simplest most flexible manner is to be preferred, if not mandatory.

WOUNDS AND INJURIES OF SOFT TISSUES

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